



California Institute of Technology



Flexible Electronics for Space Applications

**Material Research Society
Flexible Electronics Symposium
San Francisco, CA**

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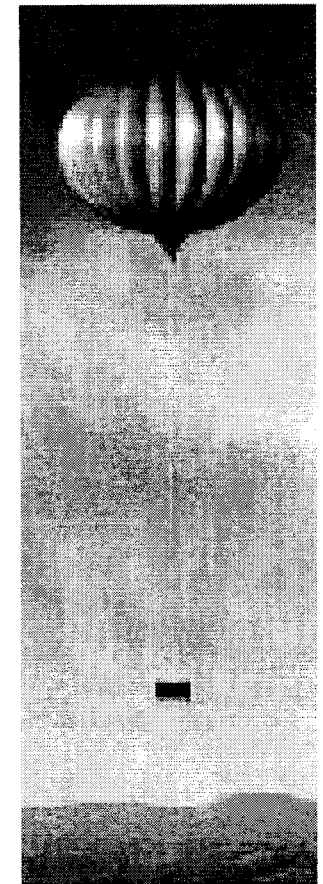
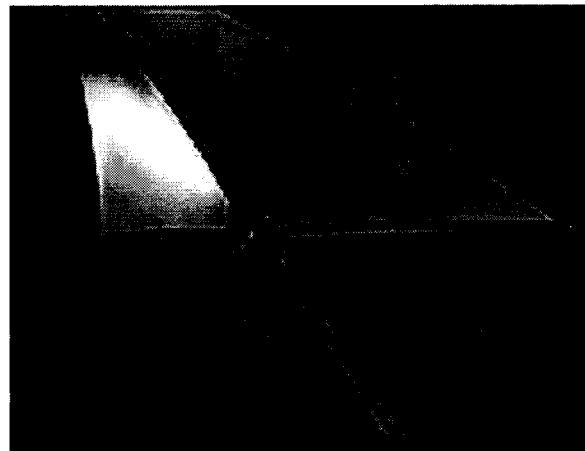
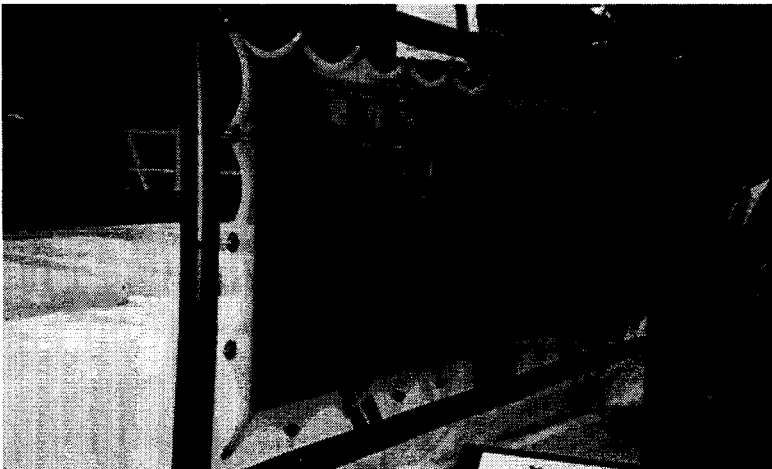
**David Binkley, Nikhil Verma and Robert Crawford
*University of North Carolina, Charlotte***

Why flexible electronics for space?

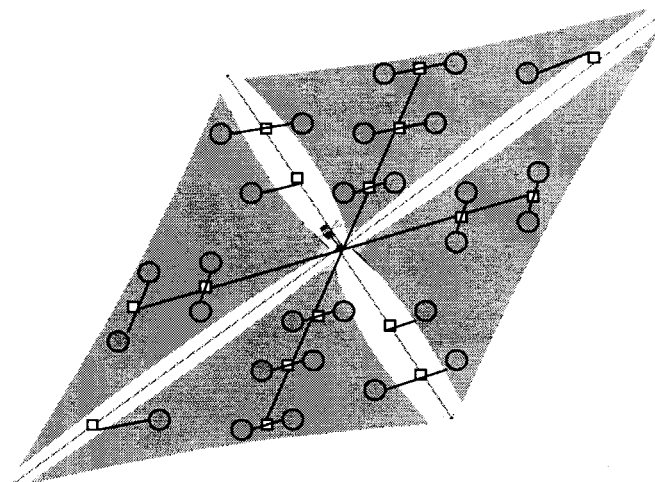
Space durable sensing capabilities are needed for very thin, large area deployable structures ✓

Distributed sensing and control has been identified as a key requirement for numerous NASA missions:

- Solar sails (health monitoring, shape sensing)
- Balloon missions (health monitoring, strain sensing)
- Synthetic aperture radar (shape, temperature sensing)
- Optical telescopes (shape, temperature sensing)



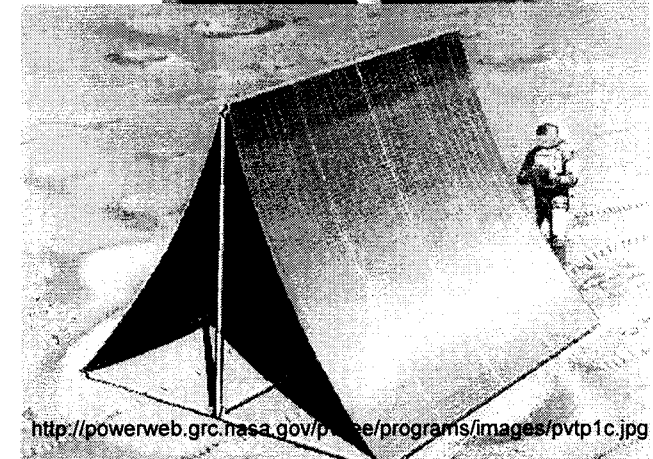
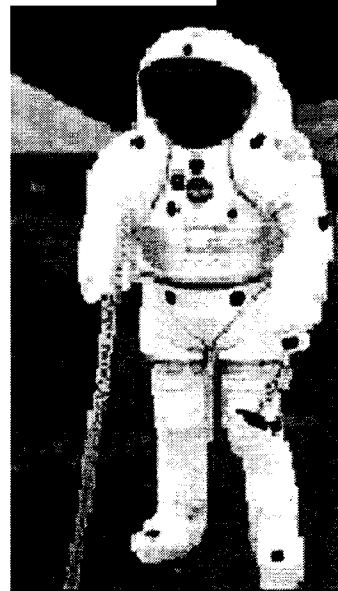
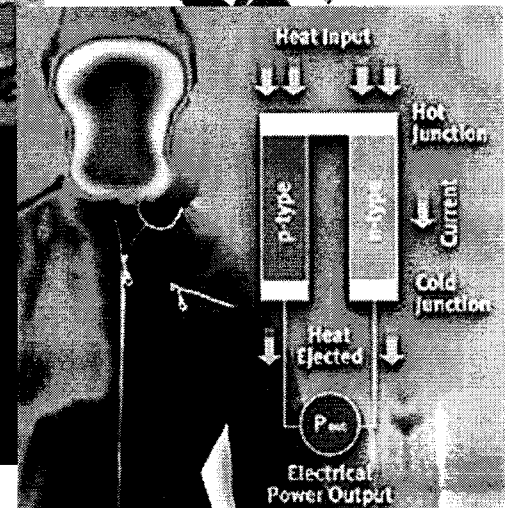
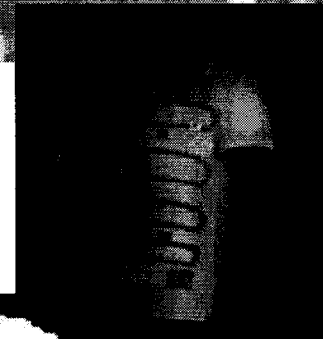
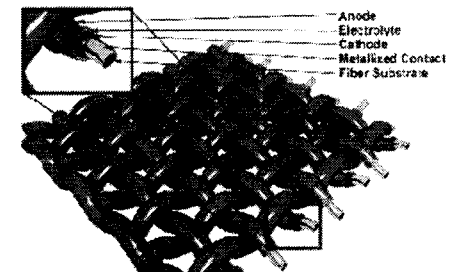
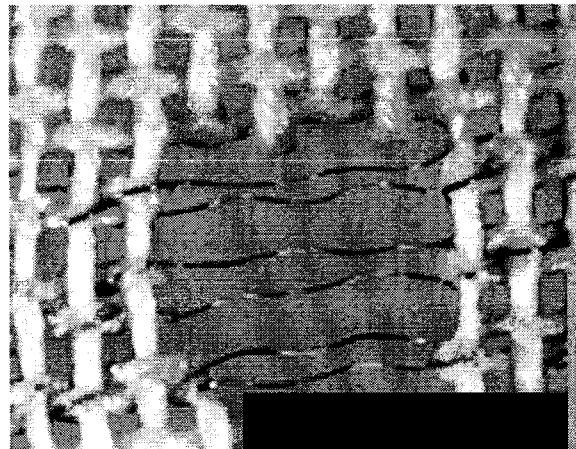
- **How do we integrate robust sensing electronics with thin, large structures?**
 - Thin substrates (<2 mils)
 - Rough substrate (300 nm rms)
 - Maintain low areal density (0.4 g/m²)
 - Large areas (100 m x 100 m)
 - Hundreds to thousands of sensor nodes
 - Minimal perturbation/good CTE match
 - Space durable
 - Low power
- **How do we obtain a useful signal and distribute this to the appropriate node ?**
 - *Integrated signal processing electronics are key to maximum functionality*
 - Sensor placement (how many and where do we put them?)



Solar sail with distributed sensing nodes

Electronic textiles and fabrics

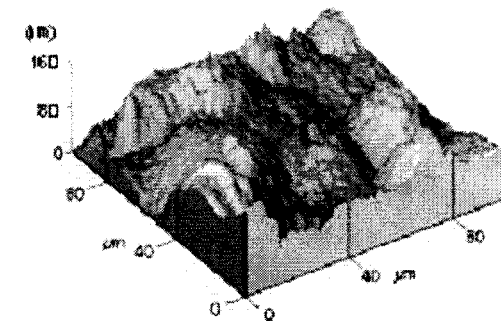
- **Proposed commercial applications:**
 - Integrated heating/cooling
 - biomedical monitoring
- **Applications to space:**
 - Advanced spacesuits and with integral health monitoring sensors and environmental control
 - Integrated high capacity communications
 - Smart systems monitoring, control, caution, & warning
- **Embedded electronics and power harvesting:**
 - Roll-up solar cells and tents
 - Deployable habitats



<http://powerweb.grc.nasa.gov/power/programs/images/pvtp1c.jpg>

- **Fabrication of devices on flexible, polymer substrates**

- Polyimide surface micro-roughness (not pristine substrates)
- Quality of semiconductor (which impact mobility)
- Quality of gate dielectric



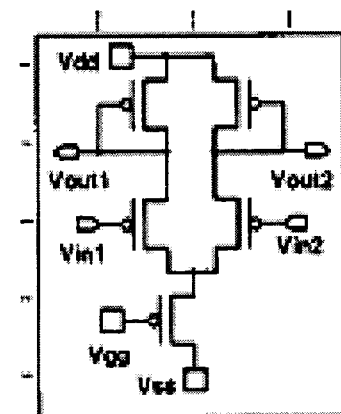
AFM of Pristine polyimide surface

- **Reliability of TFT devices**

- Evaluate relevant materials (organics, a-Si-H)
- Radiation tolerance
- Mechanical properties

- **TFT Circuits**

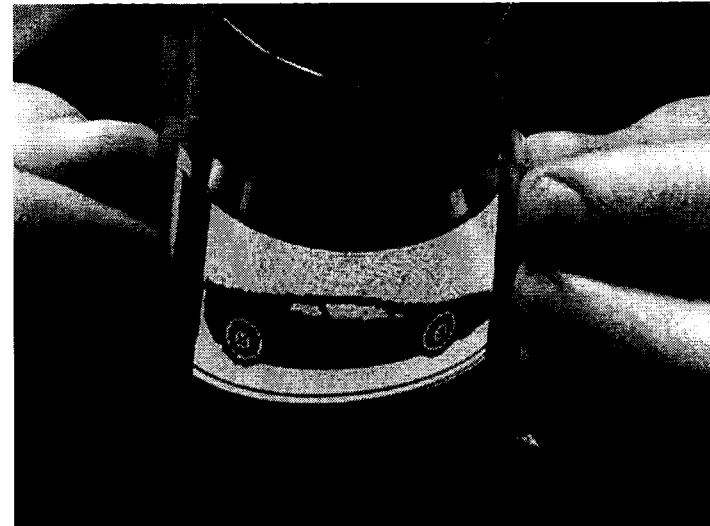
- Design of op amps for signal processing
- Low TFT transconductance
- High input offset bias, low amplifier gain
- Development of TFT based multiplexing circuits



TFT amplifier

- Commercial focus:
 - Low cost
 - High volume
 - Expendable
- NASA needs:
 - Long term space durability
 - High reliability
 - Robust operation

Bottom line: Can't rely on current commercial efforts to address NASA requirements



Flexible displays

IEEE Spectrum, August 2000

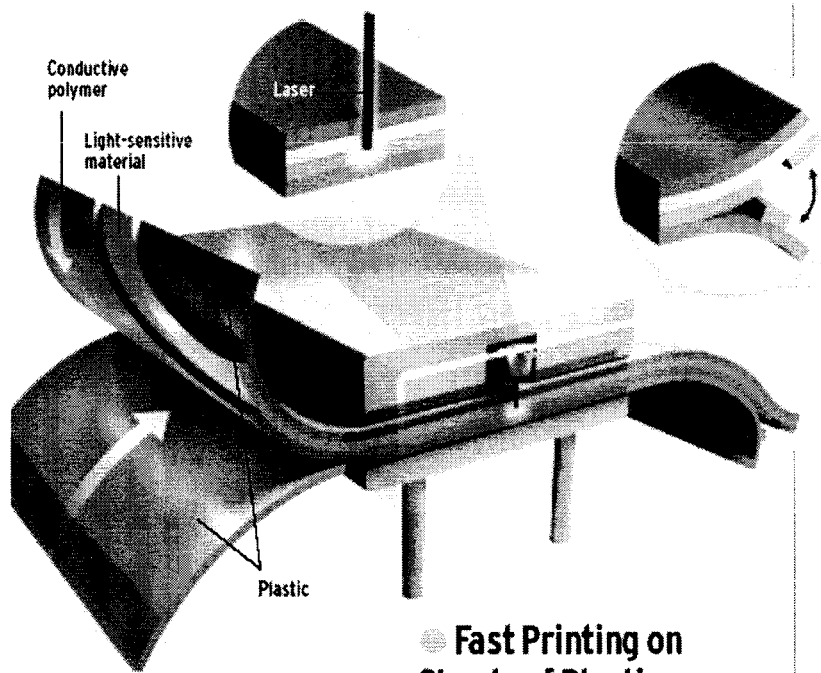


Electronic paper



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Roll-to-roll processing to eliminate assembly

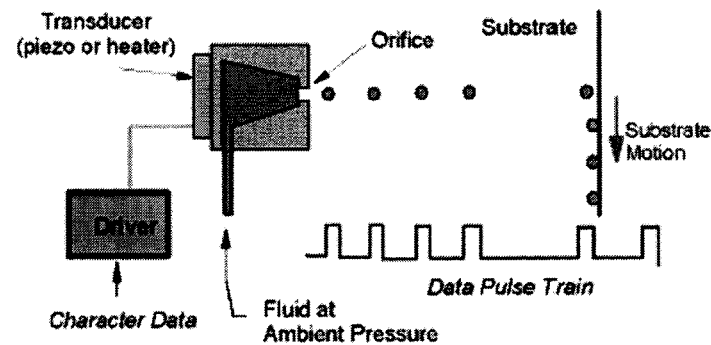


● Fast Printing on Sheets of Plastic

Roll to roll processing

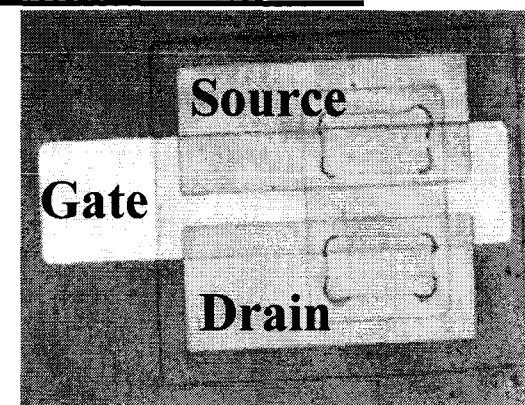
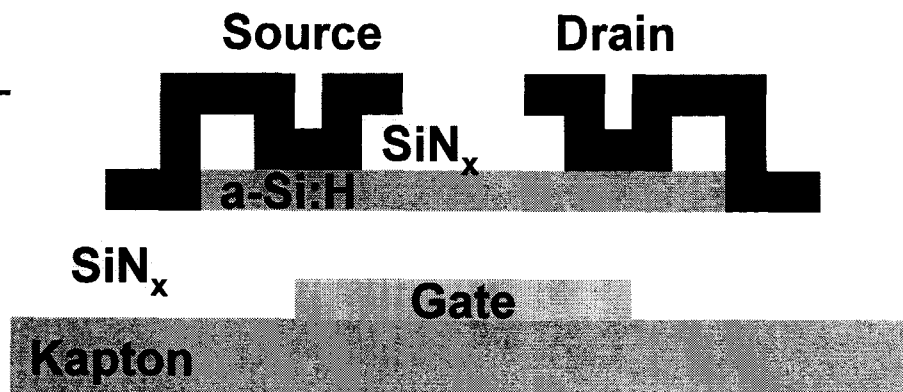
Ink jet printing

Demand Ink-Jet Technology



MicroFab Technologies, Inc.

a-Si:H thin film transistors

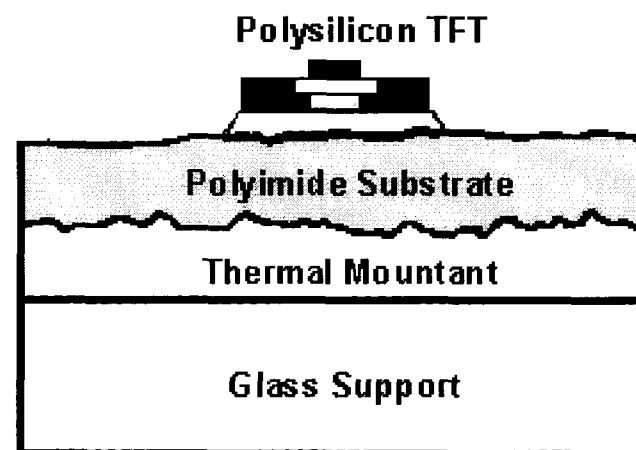


TFT top view

Typical Penn State TFT fabrication on polyimide:

1. DC sputter 100 nm Mo/Al/Mo gate contact and pattern via lift-off lithography
2. Deposit 300 nm silicon nitride gate dielectric layer from a SiH_4 and NH_3 gas mixture at 100 W/cm², 0.5 torr and 250°C (PECVD)
3. Deposit 50 nm a-Si:H using pure SiH_4 at 5 mW/cm², 0.5 torr and 250°C (PECVD)
4. Deposit 300 nm silicon nitride passivation layer (PECVD)
5. Isolate active regions via lithography and CF_4 RIE
6. Pattern openings and deposit 50 nm n+ microcrystalline a-Si:H with SiH_4 , PH_3 and H_2 at 425 mW/cm², 0.5 torr And 250°C (PECVD)
7. Deposit top 30 nm Mo and 30 nm Al top contacts, and
8. Pattern using lift-off photolithography
9. Etch excess n+ microcrystalline a-Si:H regions using CF_4 RIE

<u>substrate</u>	<u>mobility, cm²/V-s</u>	<u>threshold voltage, V</u>
glass	1	0.1
polyimide	0.7 to 1	5



PSA to glass used to improve flatness



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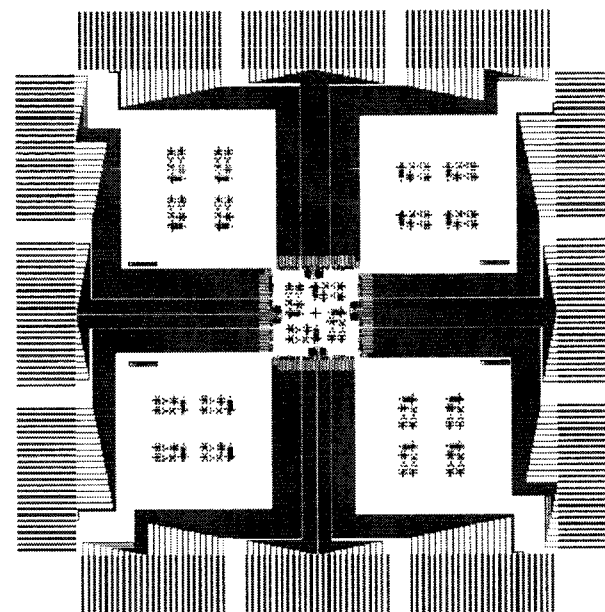
TFT sensor arrays – Penn State



PENNSSTATE

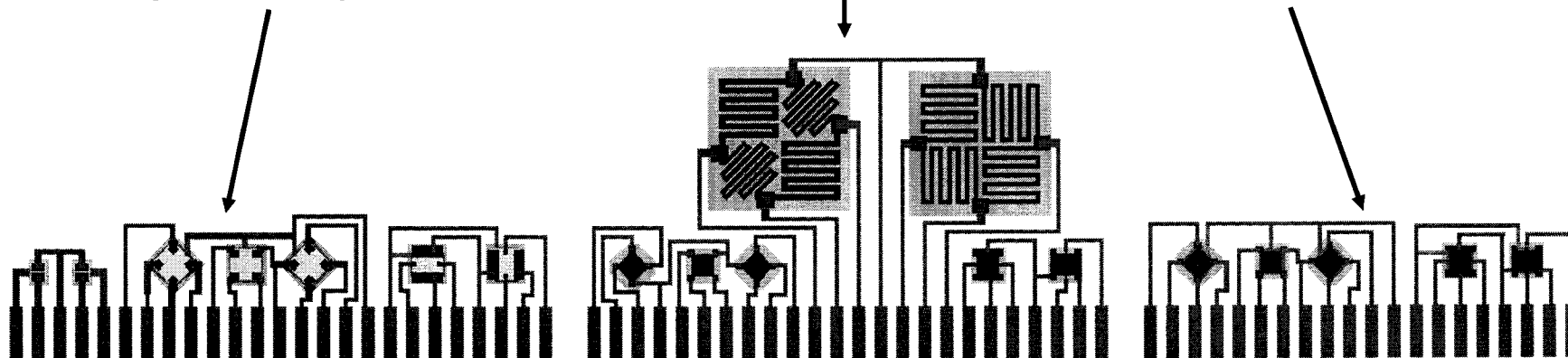


Ungated N⁺ sensing element

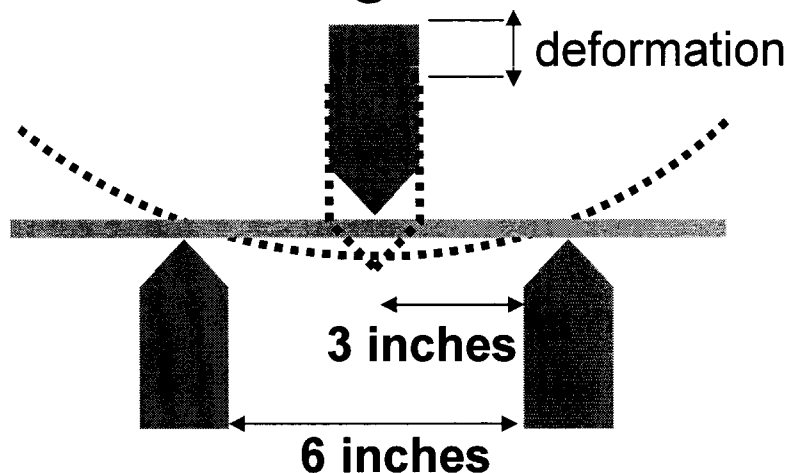


Gated A-Si:H sensors
(bending, shearing, and TFTs)

Gated N⁺ sensing element
(Bending and shearing)

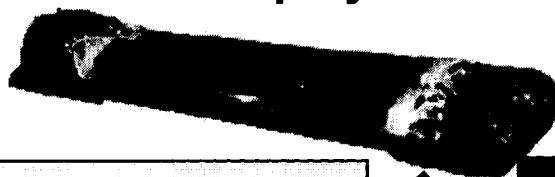


Bending Stress Test

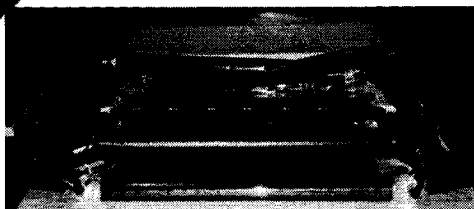


Three point bending test, 100 cycles
Haversine waveform, 0.25 Hz
1.18 inch deformation

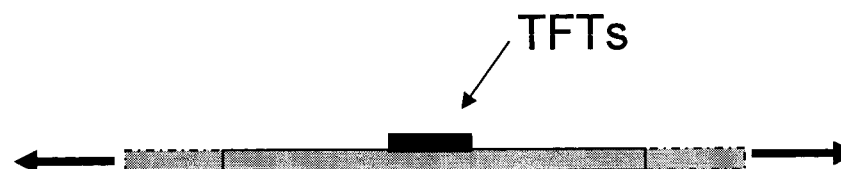
Used to represent unrolling during deployment



Attempting to replicate service conditions

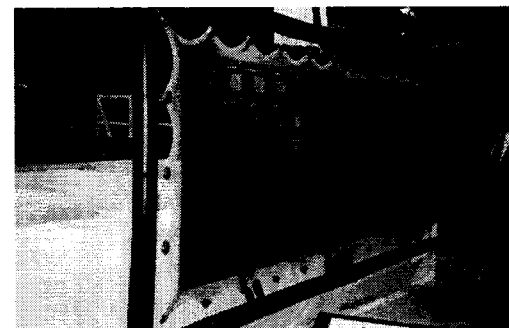


Tensile Stress Test



Uniaxial stress test
2000 psi
Hold 1 hour

Represents tensioning during deployment

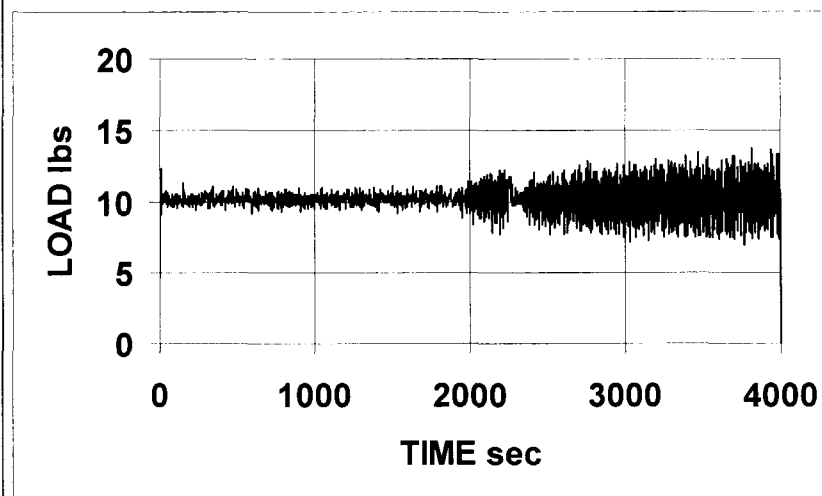
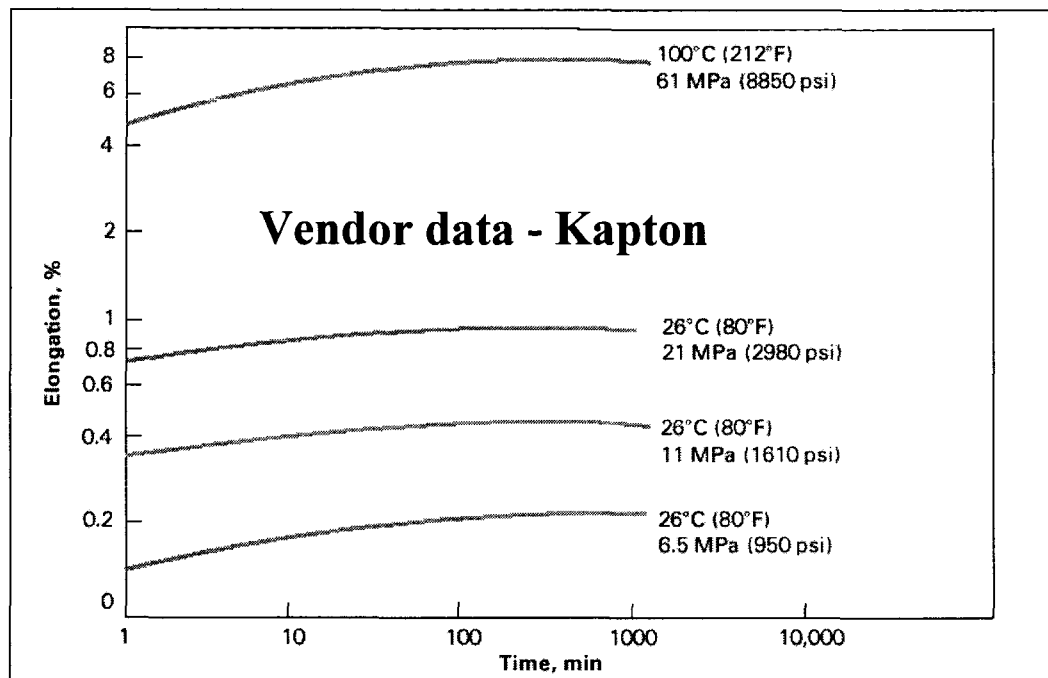




Mechanical testing of TFTS on flex



Tensile Creep Properties, Type HN Film, 25 μ m (1 mil)



Load vs. time (uniaxial stress test)

Concerned with viscoelastic effects, creep:

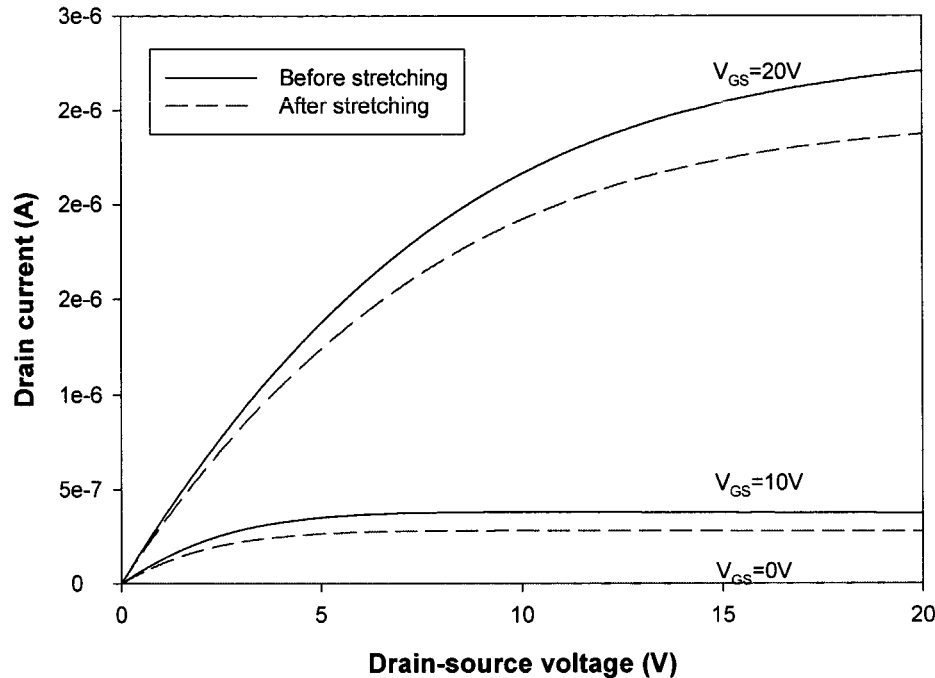
- Delamination of thin film structures on polyimide?
- Effects at low temperature?



Initial results of mechanical testing

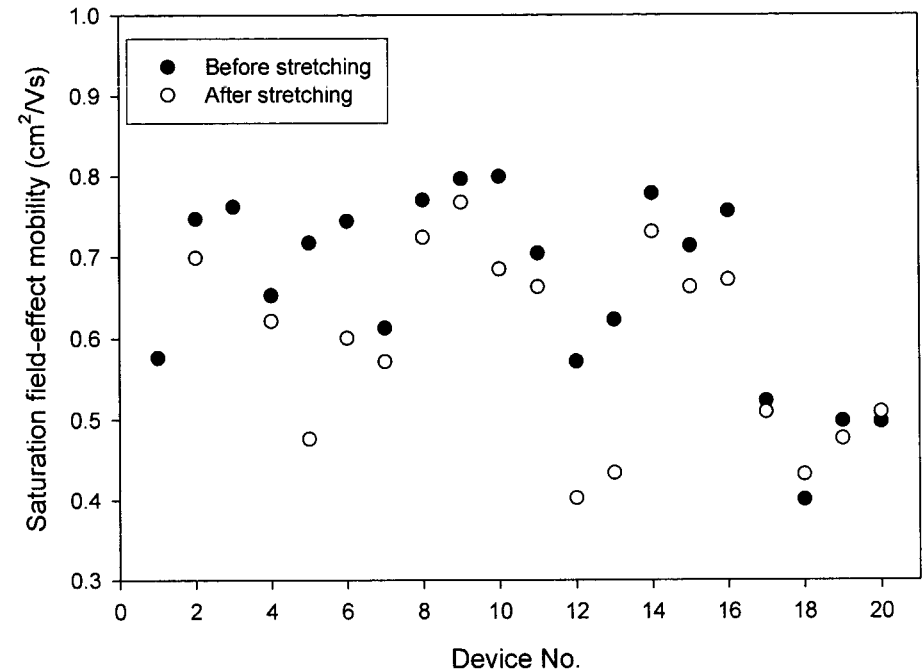


R2C4 W/L=40/24 μ m



TFT output characteristics
before and after tensile stress

Field-effect mobility before and after stretching

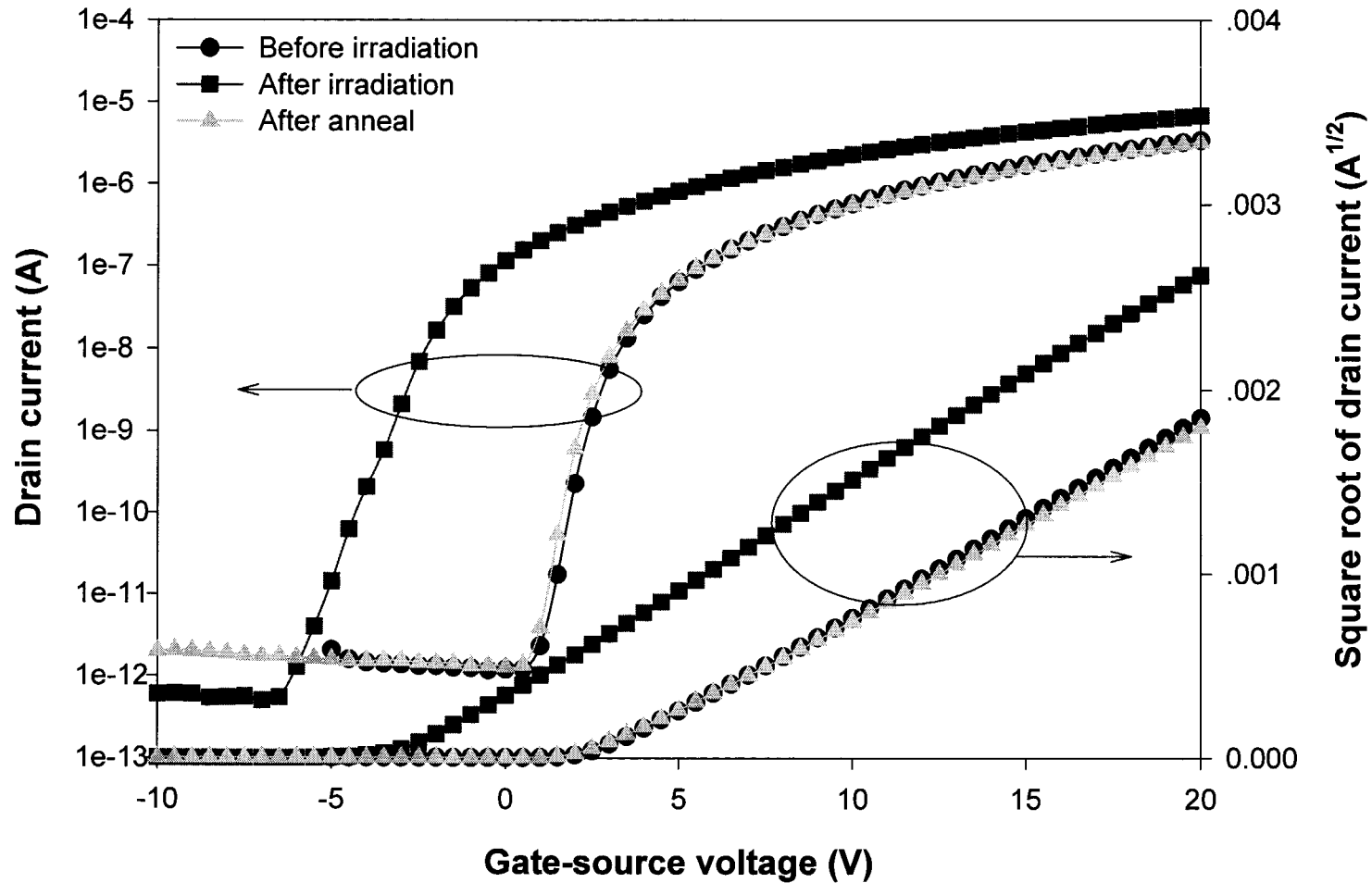


Field effect before and after tensile stress

Recent test results:

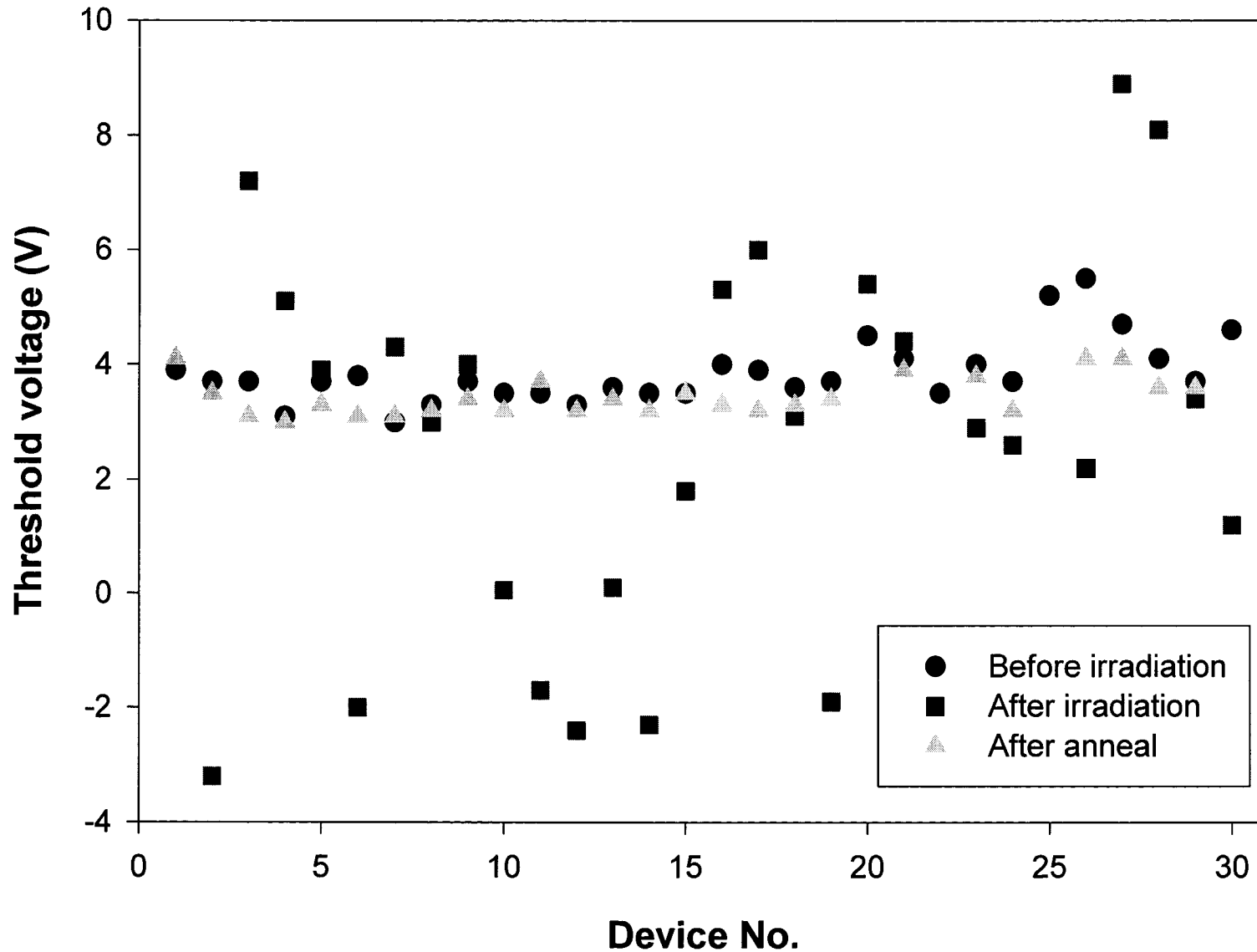
- 2,500 psi uniaxial tension for 60 minutes
- 20 a-Si:H TFTs on polyimide characterized
- 90% of TFTs survived
- 70% TFTs exhibited minor changes in mobility and V_t

R3C5 W/L=40/24 μ m

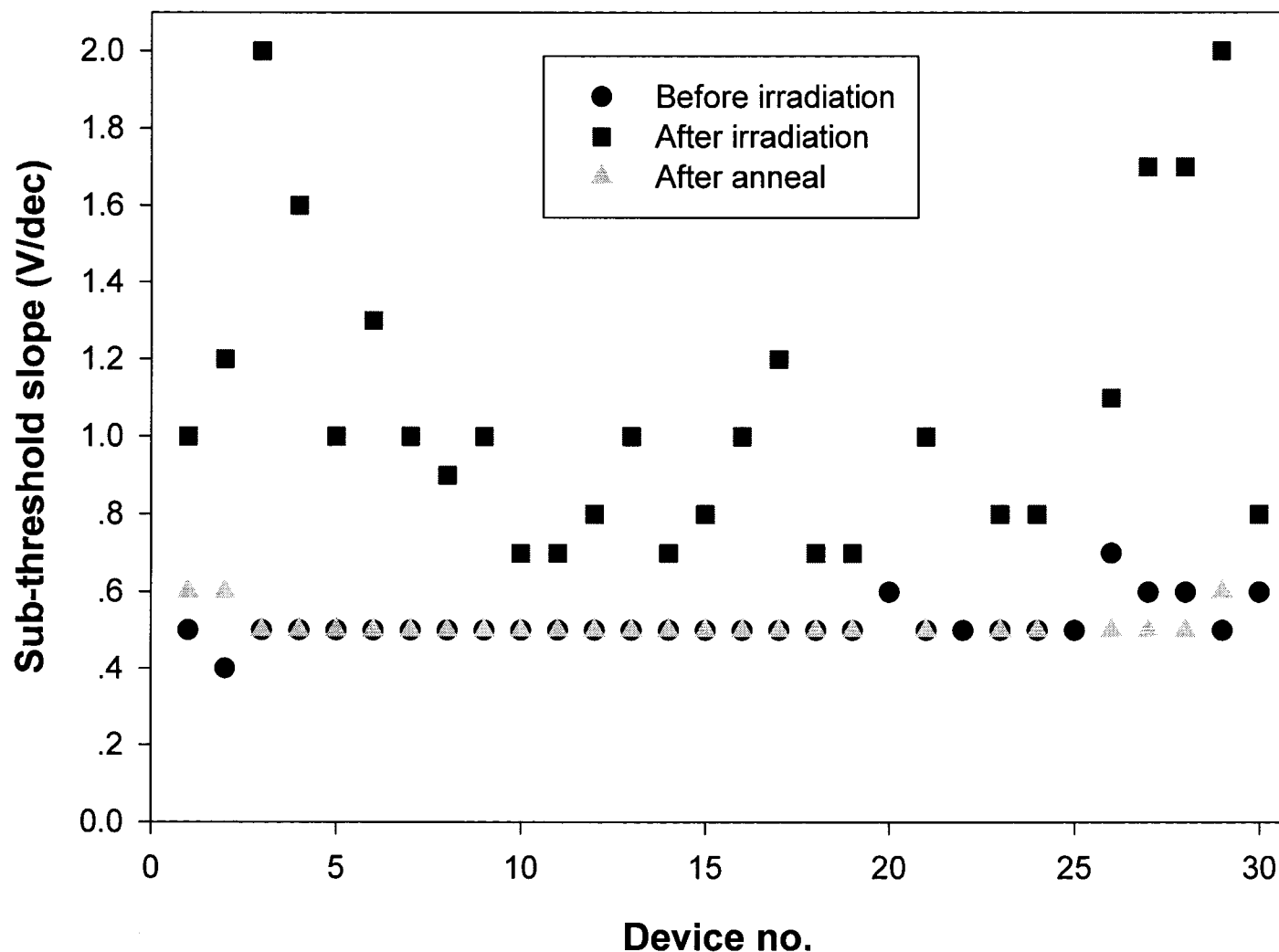


1 MeV electron beam, 1 Mrad (Si) total dose, Current = 8.5 μ A

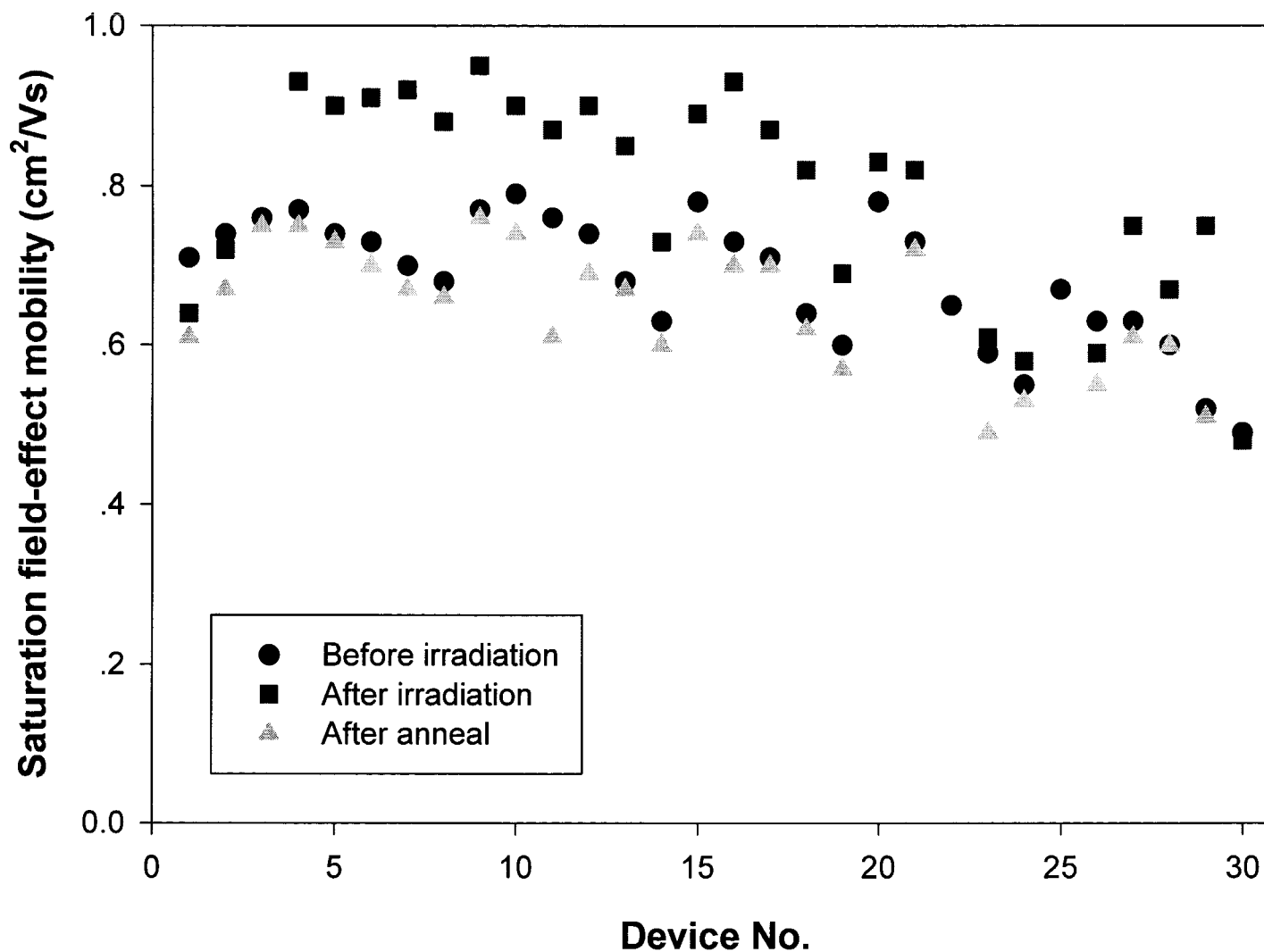
TFT threshold voltage before and after irradiation anneal



TFT sub-threshold slope before and after irradiation and anneal

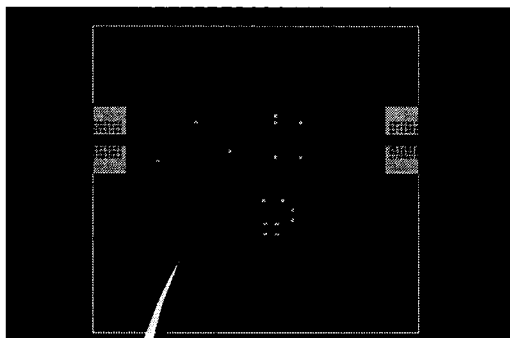


TFT saturation field-effect mobility before and after irradiation



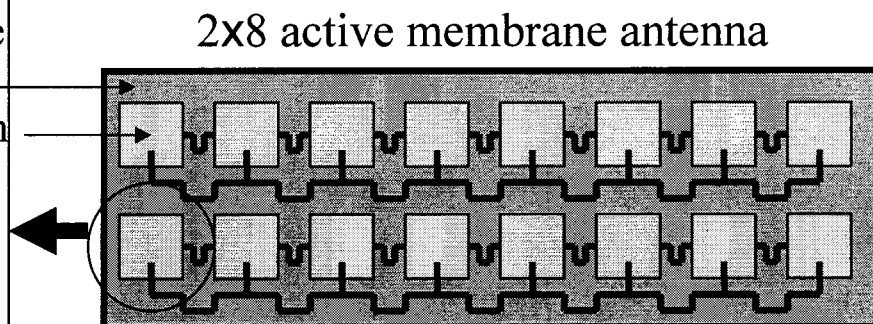
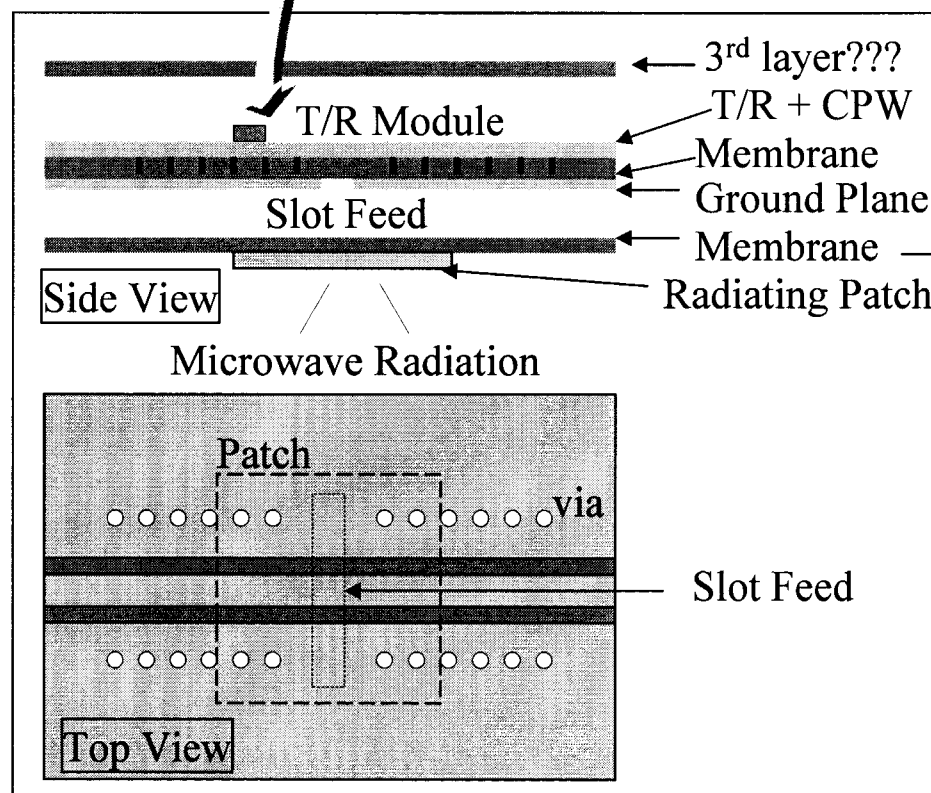
Synthetic aperture radar application

T/R layout developed by ACT/code Y funding



Goals:

- Demo a 2x8 active membrane antenna
- Flip-chip on flex
- Feed design
- RF interconnects



Kapton thickness: 2mils
Copper thickness: 5 - 12um
Layer spacing: 1.25cm

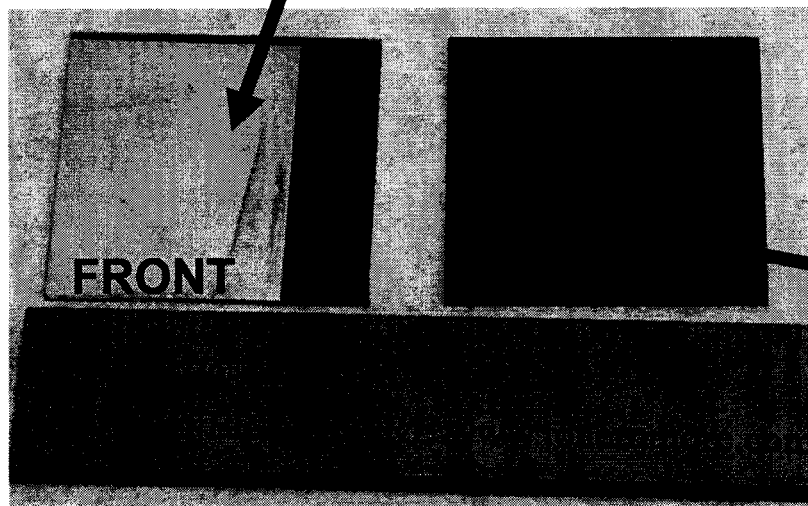
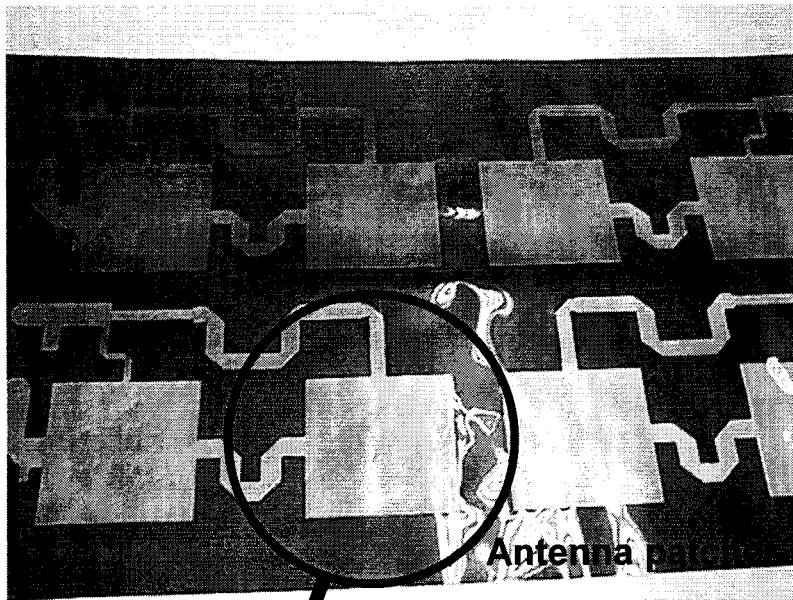


Fabrication of TFTs on patch antenna array

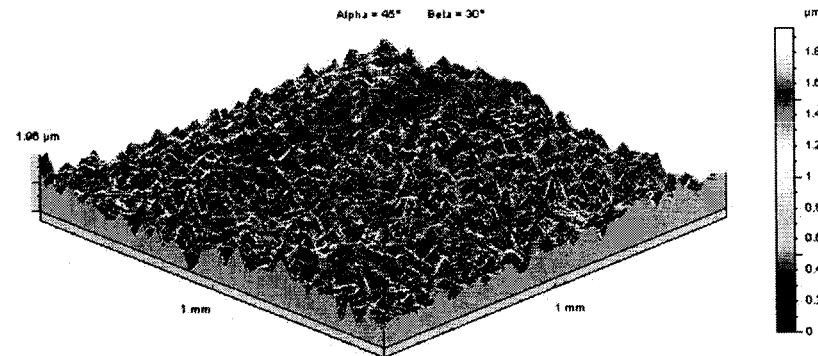


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Synthetic Aperture Radar Transmit/Receive structure:



Fabrication of a-Si:H TFTs on back of patch



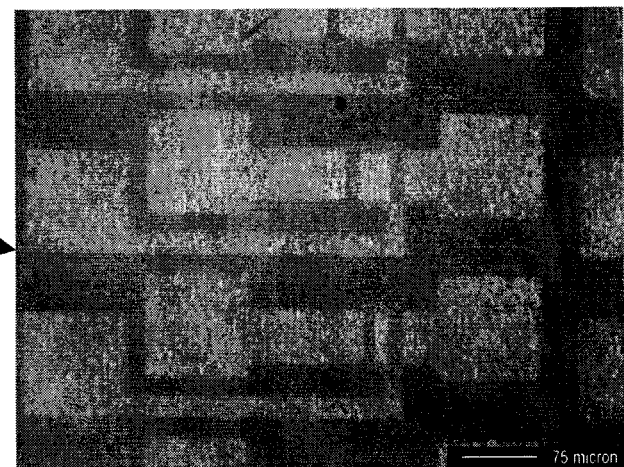
profilometry of etched Kapton AP

Typical substrate roughness values:

Glass-0.5 nm rms

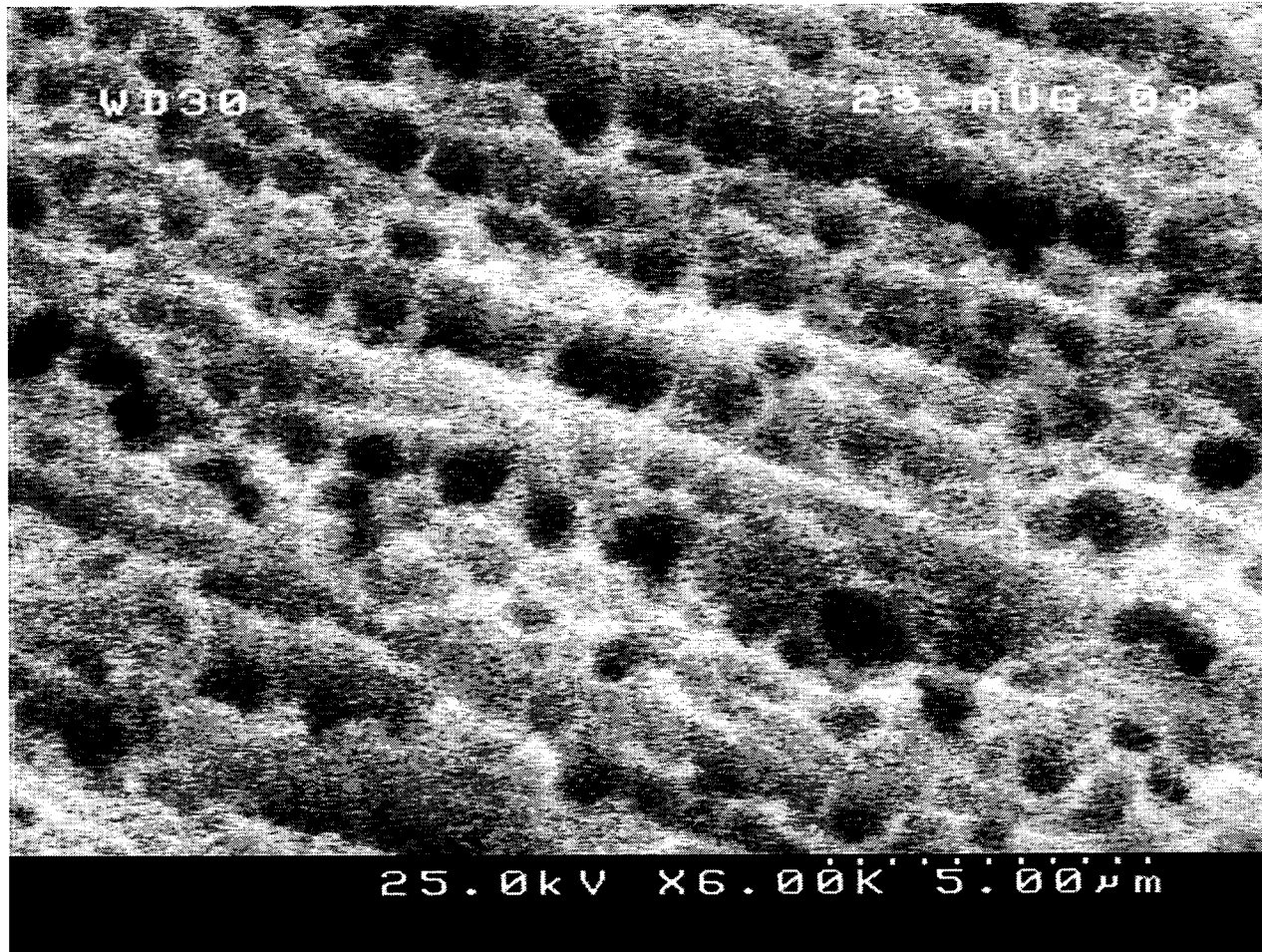
Pristine polyimide-30 nm rms

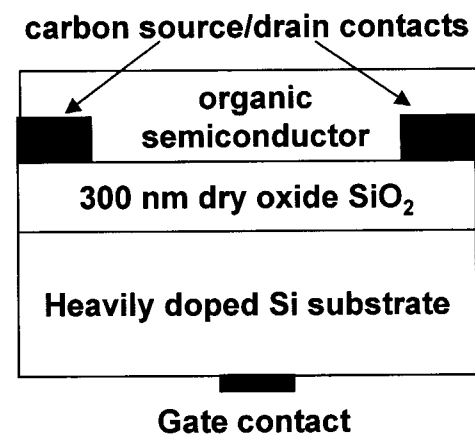
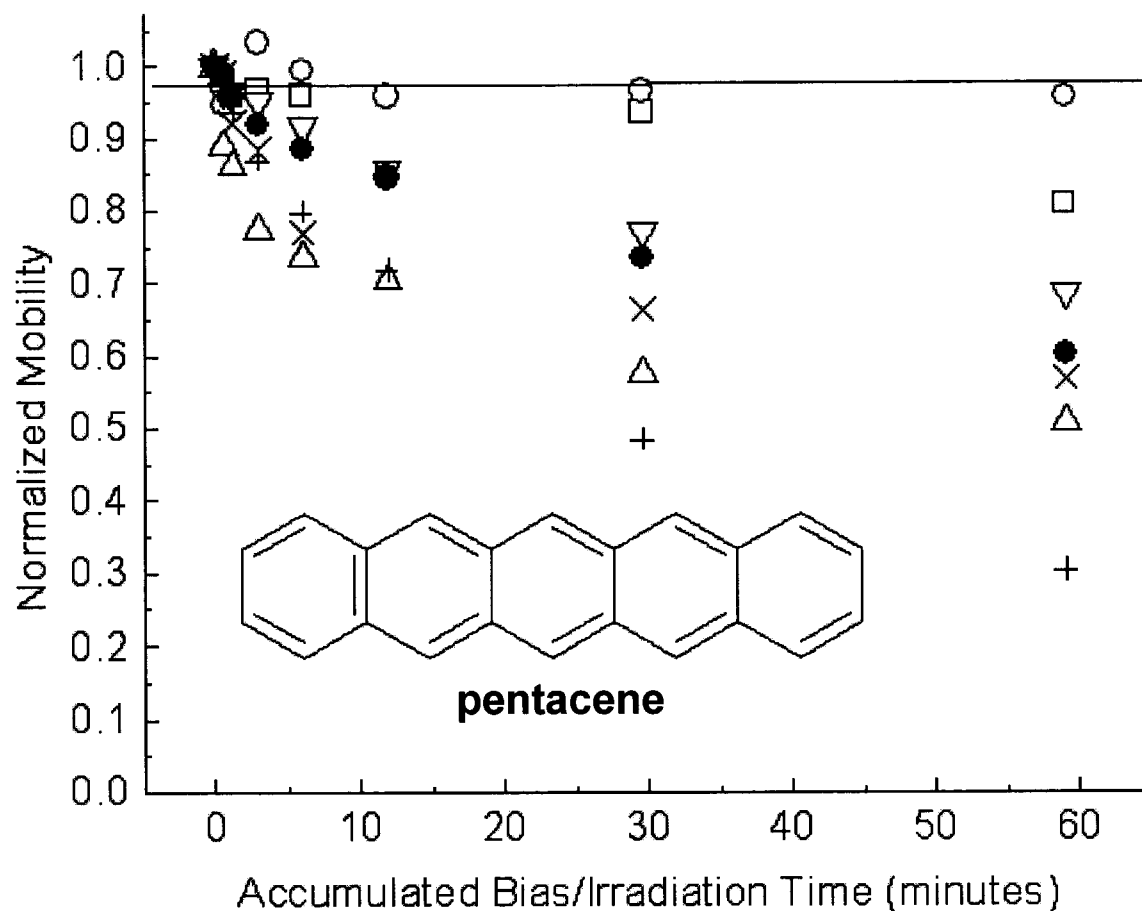
Processed polyimide-300 nm rms

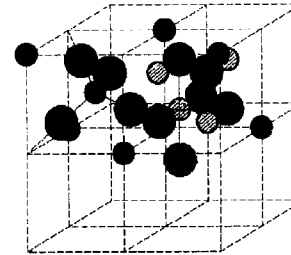
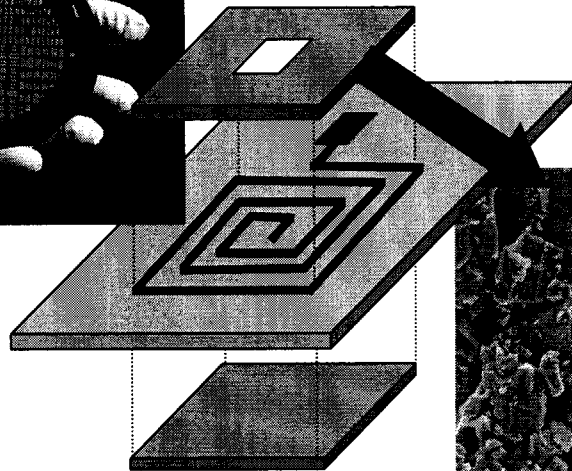
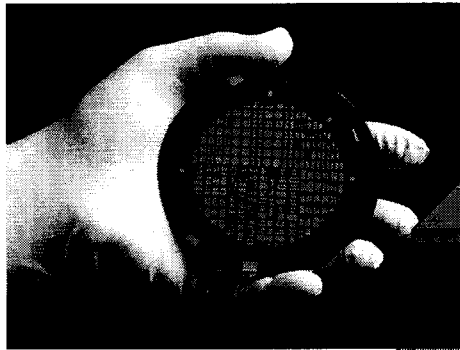


TFTs on Kapton patch

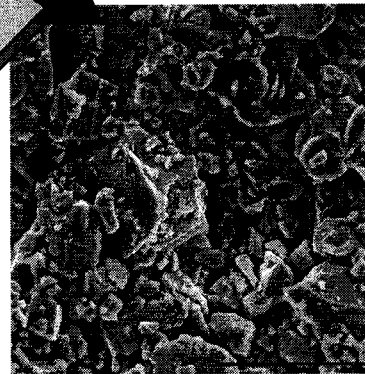
SEM of etched polyimide



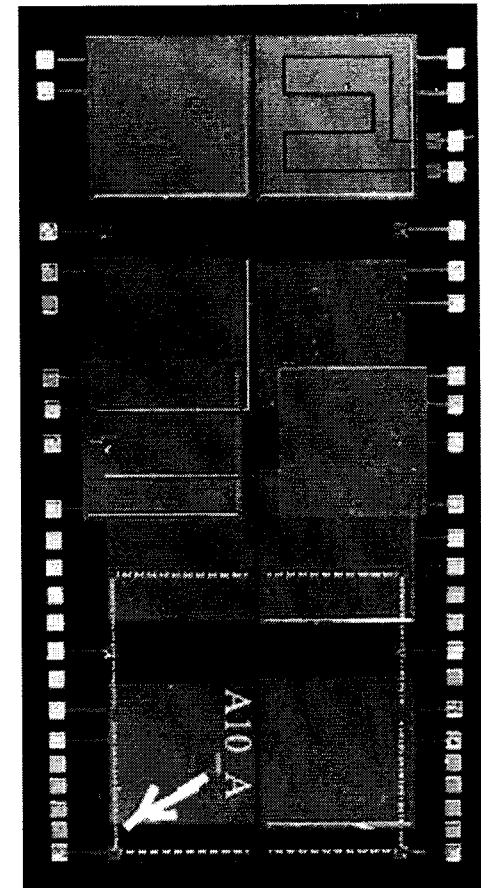




Ferrite material



**Ceramic-polymer magnetic
materials on flexible substrates
for integrated inductors**



**Multi-layer thin film capacitors
and resistors**



Summary



- Large area space structures will require a new approach to the integration of electronics for health monitoring and sensing
- Emerging technologies in flexible electronics and materials provide a means to integration of these new functions, *but they must be developed with the relevant space environment in mind*
- Initial radiation and mechanical tests look promising, indicate areas that must be addressed for developing robust TFT-based electronics
- Processes must be developed for integration of devices with the real structures, to provide sufficient yield
- Continuing with development of appropriate TFT-based sensors and sensor electronics